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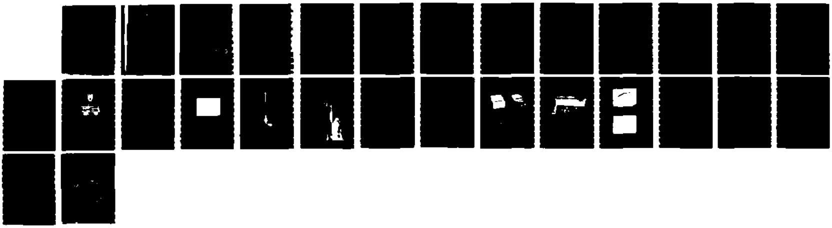

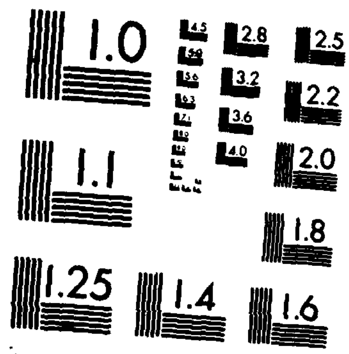

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Aero Propulsion Technical Memorandum 433

DEVELOPMENT OF A FAST RESPONSE INTAKE AIR TEMPERATURE RECORDER FOR THE MIRAGE IIIO AIRCRAFT

by

W. H. HARCH

Approved for Public Release

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DEVELOPMENT OF A FAST RESPONSE INTAKE AIR TEMPERATURE RECORDER FOR THE MIRAGE IIIO AIRCRAFT

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W.H. HARCH

SUMMARY

The development and operation are described of a fast response temperature probe and associated instrument package for the in-flight recording of air temperature variations in the inlet to the Atar 09C engine of the Mirage IIIO Aircraft.

POSTAL ADDRESS: Director, Aeronautical Research Laboratories,
P.O. Box 4331, Melbourne, Victoria, 3001, Australia.

CONTENTS

1. INTRODUCTION

In-flight ingestion of missile exhaust efflux or gun gas tends to cause instability in an aircraft turbine engine, usually due to the reaction of the engine compressor to associated inlet temperature fluctuations. The temperature transients involved are generally too rapid to permit measurement with conventional instrumentation.

As part of a broader investigation of the sensitivity to missile firings of the ATAR 09C engine in RAAF Mirage IIIO (Refs 1-4), a system was developed for in-flight fast response measurement and recording of temperature variations at the compressor face of the engine in that aircraft.

ATAR 09C engine in the RAAF Mirage IIIO

to next to last line

2. CONCEPT

The requirement was for a complete system including sensing probes, recording and data retrieval equipment for use in missile firing trials. In addition to the size, weight and flightworthiness constraints imposed on any airborne instrumentation package, a number of other constraints existed due to the limited time which was available for development (three weeks) and installation. The package was to be self-contained with no input from the pressurized area, aircraft power, pilot or aircraft systems. The package could be switched on only with other trials instrumentation at the beginning of the flight. Therefore the recording period had to be approximately 1 hour to ensure capture of transients that occurred during missile firings in the aircraft sortie.

Under these constraints, the system options were quickly reduced to thermocouple type sensors and magnetic tape recorders.

3. SENSOR DEVELOPMENT

3.1 Thermocouple Configuration

Initial estimates of the temperature transients likely to be encountered indicated rise times of the order of 0.1 secs. For the temperature ranges involved K type (chromel-alumel) thermocouples were judged to be suitable. To maximise frequency response whilst retaining reasonable strength, exposed thermocouples were manufactured from 0.12 mm diameter wire, spot welded at the junction (Fig 1). By carefully minimising the bulk of the welded junction, it was hoped to approximate the response of butt welded exposed thermocouples, for which commercial literature indicated a time constant of 0.08 seconds at atmospheric pressure and temperature in a 20 m/s air stream. Estimation of the time constant at operational conditions is described in the following section.

3.2 Theoretical Calculation of Response Time

Suppose a thermocouple is exposed to a flow in which the temperature is increased instantaneously from θ_1 to θ_2. Assuming that there is no internal generation of heat in the thermocouple, the response of the thermocouple can be written

$$mS_w \dot{\theta}_w = q \qquad 3.1$$

where m = mass of thermocouple
S_w = specific heat of thermocouple
$\dot{\theta}_w$ = temperature rise rate of thermocouple
q = heat transfer rate to thermocouple

The instanteneous temperature variation across the thickness of the wire is assumed to be negligible. Furthermore, the length/diameter ratio of the thermocouple loop (approx 50) was such that conduction along the wire could be neglected. Assuming also that the only mechanism of heat transfer from the air to the thermocouple is forced convection, Equation 3.1 may be rewritten, for unit length of wire:

$$\rho_w \cdot \frac{\pi d^2}{4} S_w \dot{\theta}_w = h\pi d \ (\theta_2 - \theta_w) \qquad 3.2$$

where ρ_w = density of thermocouple wire
d = diameter of thermocouple wire
h = convection heat transfer coefficient

Or simplifying to the form 3.3:

$$\dot{\theta}_w = \frac{4h}{d} \cdot \frac{1}{\rho_w} \cdot \frac{1}{S_w} \ (\theta_2 - \theta_w) \qquad 3.3$$

Equation 3.3 may be solved to give equation 3.4:

$$\theta_w = \theta_2 - (\theta_2 - \theta_1)\ e^{-t/\tau} \qquad 3.4$$

where $\tau = \dfrac{d\rho_w S_w}{4h}$

(The response time constant τ is the time for $(\theta_w - \theta_1) = 0.63\ (\theta_2 - \theta_1)$)
For convective heat transfer the non-dimensional Nusselt number Nu_f (at film temperature) is defined by 3.5:

$$Nu_f = \frac{hd}{K_f} \qquad 3.5$$

where K_f = Thermal conductivity of fluid

Therefore the time constant τ can be written

$$\tau = \frac{d^2\ \rho_w\ S_w}{4\ Nu_f\ K_f} \qquad 3.6$$

For forced convection over cylinders from Corrsin (Ref 5)

$$Nu_f = 0.42\ Pr^{0.2} + 0.57\ Pr^{0.33}\ Re^{0.5} \qquad 3.7$$

where Pr = Prandtl Number
Re = Reynolds Number

which for air (Pr = 0.71) reduces to

$$Nu_f = 0.39 + 0.51\ Re^{0.5} \qquad 3.8$$

Therefore

$$\tau = \left(\frac{d^2 \rho_w S_w}{4K_f}\right) \cdot \left\{\frac{1}{0.39 + 0.51 \, Re^{0.5}}\right\} \qquad 3.9$$

The time constant τ may therefore be evaluated for various conditions. For example, for 0.12 mm diameter type K thermocouple:

(1) Sea Level, 20°C, 20 m/s air velocity — τ = 0.079 secs
(In confirmation of commercial Literature data)

(2) Sea Level, 20°C, 53 m/s air velocity — τ = 0.048 secs
(Experimental rig, see Section 3.3)

(3) ARDU Tropical Atmosphere 8000 ft Altitude
air velocity, 165 m/s — τ = 0.028 secs
(Calculated Atar engine intake conditions
at proposed trial altitude)

This indicated that the proposed thermocouples should have sufficiently rapid response, provided that the theoretical performance could be realised.

3.3 Measurement of Thermocouple Response

Since thermocouple response time was a critical property of the system, a small rig (Fig 2) was constructed to enable testing of both individual thermocouples and the complete instrumentation package.

The rig provided two adjacent air streams of matched velocity (53 m/s), one of which was heated to approximately 69°C above ambient conditions. The thermocouple could be rapidly traversed across the shear layer by a spring loaded mechanism. Measurement of the steady state temperature profile (Fig 3) together with the traverse velocity (0.9 m/s at the shear layer determined by integration of the output of an accelerometer attached to the probe) indicated that the thermocouple was subjected to a flow in which there was a temperature rise from 10% to 90%

of final value in 0.0006 seconds. This was approximately 2 orders faster than the thermocouple response rate and therefore effectively a step input.

A typical thermocouple response is shown in Fig 4. While individual thermocouples yielded more rapid response than that shown, an average time constant of 0.08 seconds could be guaranteed.

3.4 Correction of Theoretical Values

The measured thermocouple response (τ_M = 0.08 sec) was about 1.7 times the calculated theoretical response (τ_T = 0.048 sec) derived from equation 3.9. The difference between the theoretical and experimental measurements was considered to be primarily in the ( ) term of equation 3.9, and due mainly to the difference between specific thermocouple properties and those of the bulk material, temperature gradients in the wire and departure from the ideal cylindrical configuration. The { } term was therefore used to relate experimentally measured values to expected values at flight condition. The resultant modified prediction of response time at operational conditions (τ = 1.7 x 0.028 = 0.048 seconds) was considered adequate for the purpose.

4. PROBE DEVELOPMENT

In order to meet in minimum time the stringent structural integrity requirements for a probe located at the compressor entry face, the decision was taken to modify an existing approved pressure rake (Fig 5) (Ref 6,7).

This rake consisted of a 10 mm outside diameter stainless steel tube projecting approximately 180 mm into the airflow. Four pressure ports were located 16 mm, 64 mm, 111 mm and 172 mm from the inside wall of the engine casing. Hypodermic tubing inside the stainless steel tube connected the individual ports to a connector block located outside the engine casing.

The miniature thermocouples were mounted in the pressure ports as shown in Fig 6, with leads passing through the hypodermic tubing that led from the ports to the connector block. Two miniature type K thermocouple plugs and jacks were mounted on the connector block. The outer two thermocouples and the inner two thermocouples were wired in parallel to these connectors. A four metre lead (consisting of two pairs of thermocouple wire) was used to connect the probe to the instrument package.

The completed probe was exposed to 150 m/s airflow in a free jet testing facility to test the durability of the sensor elements, and the whole probe was subjected to an NDE inspection in the Aircraft Materials Division of ARL.

5. SIGNAL CONDITIONING

Commercially packaged thermocouple temperature transmitters are generally band limited (at frequencies less than that of interest in this application) to improve signal to noise ratios. A small circuit (Figure 7) was therefore constructed using the AD595 chip which incorporates an instrumentation amplifier and a thermocouple cold junction compensator on a monolithic chip. The amplifier has a 3dB bandwidth of 15KHz and a transfer function:

$$\text{AD595 OUTPUT} = (\text{Type K voltage} + 11\ \mu\text{V}) \times 247.3.$$

The resulting output when connected as shown in Fig 7 is 10 mV/°C at thermocouple junction (compensated for reference junction) over the range -200°C to 1250°C.

For recording purposes it was assumed that the temperature range would be -20°C to 100°C, with a corresponding modulating voltage (output of AD595) in the range -200 mV to 1 Volt DC. To facilitate the use of an AM recorder (Section 6) the output of the AD595 was first preconditioned by an AMPEX ES-100 FM Record Amplifier which produces a frequency-modulated signal output corresponding to the data input signal. The AMPEX ES-100 was set for a carrier frequency of 1.687 KHz and a 40% deviation for a 1 volt square wave.

6. RECORDER AND POWER SUPPLY

The selected recorder was a Phillips four track stereo cassette recorder modified by the Trials and Technology Support Division, Advanced Engineering Laboratory (AEL), and known as the Speech-Time Recorder (STR) (Fig 8). AEL has produced a number of these units for use in aircraft exercises. The complete recording system consists of the Speech Time Recorder, a Field Replay Unit, and a Field Master Clock. As the name suggests, the STR allows recording of speech and time as well as two channels of data.

In the present application the speech channel was used only for cassette tape annotation, although it was available for cockpit speech recording. Two channels of thermocouple data were recorded on the data tracks. A significant advantage of the system was that it already incorporated a time recording channel that allowed, in effect, event marking of the temperature data.

The Field Master Clock was set accurately to GMT and used to synchronise the clock in the recording unit. Time data from the recorder clock (Day, Hours, Minutes, Seconds) is recorded in digital format on the time track. This signal is recovered when the tape is replayed and allows correlation of temperature measurements on the data track with trials events (such as missile launch) for which time has been recorded.

A ±6 volt DC, ±12 volt DC power supply for the AD595 compensating chips and the Ampex FM modulating cards was constructed from 6 volt dry cell batteries.

The power supply, signal conditioning cards and the recorder (mounted in a foam pack to minimise shock and vibration) were installed in an aluminium box of dimensions 442 mm x 172 mm x 210 mm (Fig 9).

7. PLAYBACK

Playback was achieved using the DRCS STR playback unit and Ampex ES.100 FM playback amplifier. The time information enabled location of transient information on the tape, and the transient was easily captured by a storage oscilloscope or by direct photography of an oscilloscope trace.

8. SYSTEM TEST RESULTS

To evaluate the package a thermocouple representative of those manufactured for the probe was inserted in the test rig described in Section 3.3. This thermocouple was connected via the appropriate connectors and a thermocouple wire lead of length 4 metres (estimated length necessary to route the lead from the probe via the aircraft wheel well to the instrument package located in the gun bay) to the developed package.

The thermocouple was rapidly traversed across the shear layer while the recorder was operating. The output of the AD595 chip was also fed directly to an oscilloscope and the trace of the temperature transient photographed.

Figure 10 shows both this directly photographed trace and that recovered by playing back the recorded signal. The recovered trace contains some discernible noise, but is otherwise a faithful reproduction of the thermocouple response.

9. CONCLUSIONS

An intake air temperature probe and associated recording package has been developed for the Atar 09C engine in the Mirage IIIO Aircraft. The probe has an estimated operational time constant of 0.048 seconds (time to register 63% of final value). The probe contains four sensing thermocouples which are connected in two parallel pairs to a tape recorder. The recorder has a one hour capability and, in addition to the two thermocouple channels, contains a time track and an optional voice track. The recorder, signal conditioning and battery pack power supply are contained in an aluminium box 442 mm x 172 mm x 210 mm. Toggle switches activate the power supplies and the recording operation. Whilst the system is suitable for in-flight use, it was rapidly developed and therefore may not be the optimum in all respects. It would be an ideal prototype for a future airborne transient temperature recording system.

10. ACKNOWLEDGEMENT

The Author wishes to acknowledge the assistance of Messrs D. Mooney, M. Fisher and J. Dingley in the design and construction of this instrument.

REFERENCES

1. HQSC Minute 2602/A3/3-3(4), 21 March 1985.

2. ARL Minute S577, 10 May 1985.

3. MERRINGTON, G.L. "ATAR 09C - Missile gas ingestion and inlet temperature tolerance to stall". ARL/Aero Prop Tech Memo 431, 1985.

4. HARCH, W.H. "Matra R550 induced temperature transients in the Mirage IIIO aircraft". ARL/Aero Prop Tech Memo in course of publication.

5. CORRSIN, S. "Turbulence: experimental methods". Handbuch der Physik Vol 8, Part 2. Springer, Berlin, 1963.

6. CATCHPOLE, B.G. 'Design of a Total Pressure Rake for Flight Use in the Mirage IIIO Engine Air Intake'. ARL/ME Tech Memo 293, December 1966.

7. BUNDOCK, R.W. 'Total Pressure Distribution in the Mirage IIIO Intake' ARDU Report No 1479 Part 4, March 1968.

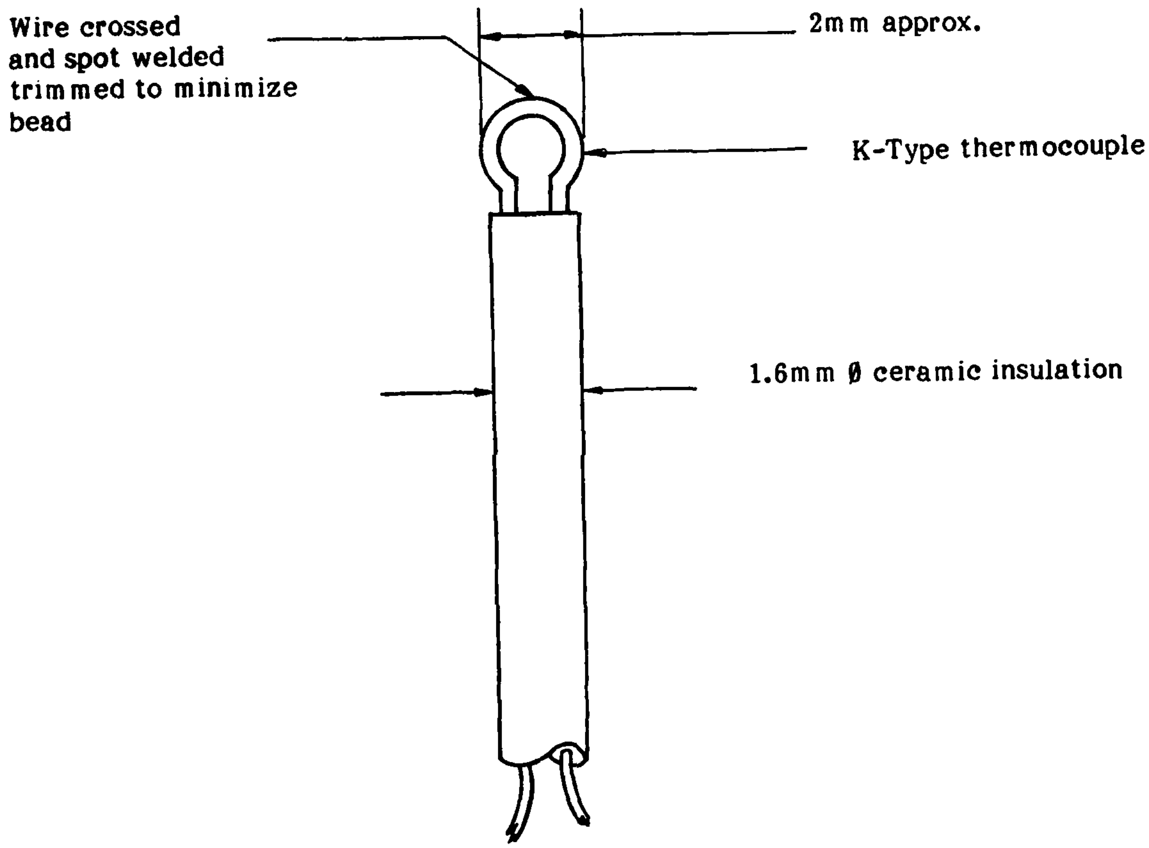


FIG. 1 FAST RESPONSE THERMOCOUPLE

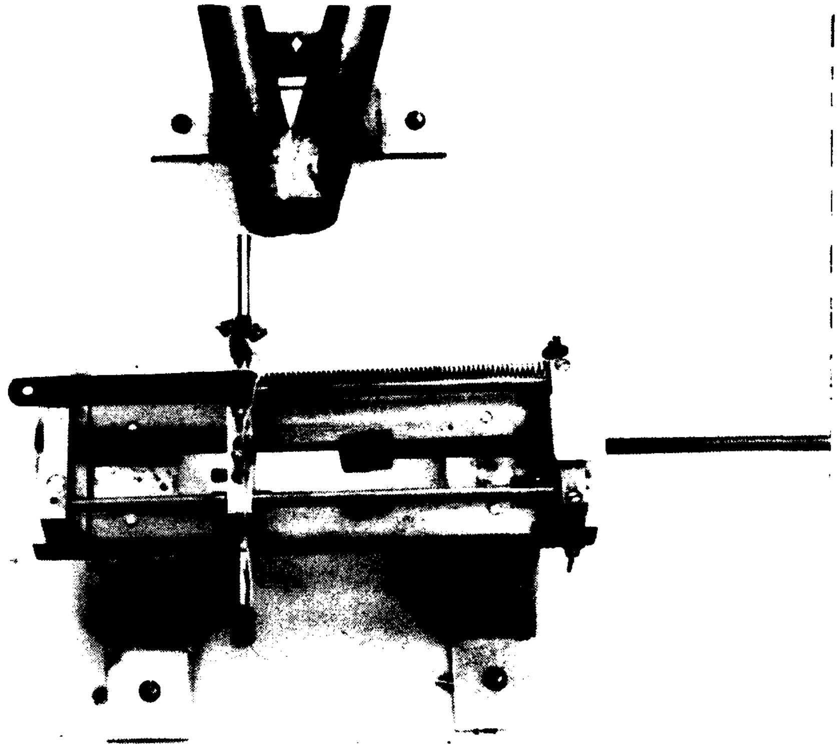


FIG. 2 TEST RIG FOR MEASUREMENT OF THERMOCUPLE RESPONSE RATES

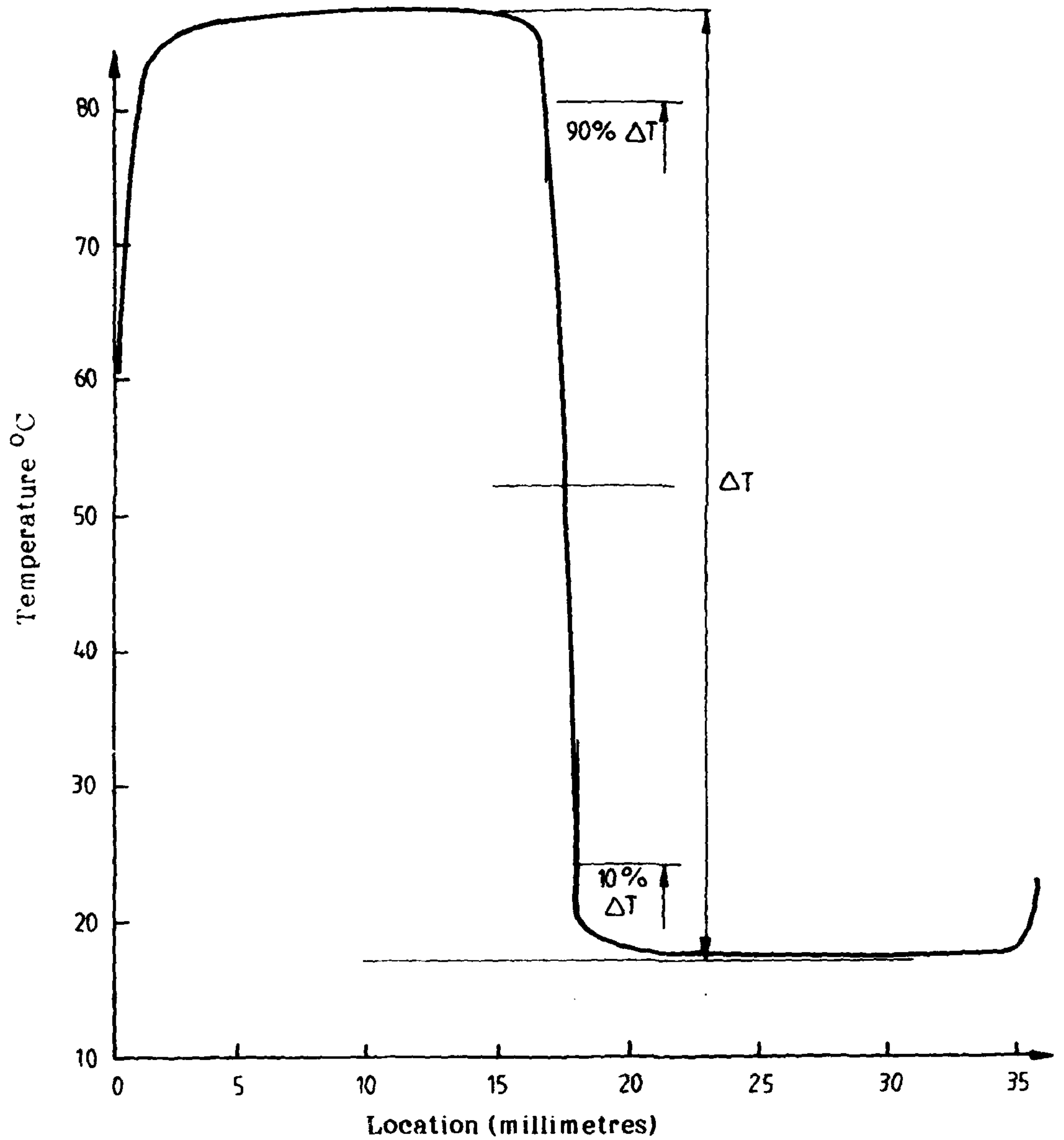


FIG. 3 TEMPERATURE PROFILE OF TEST RIG

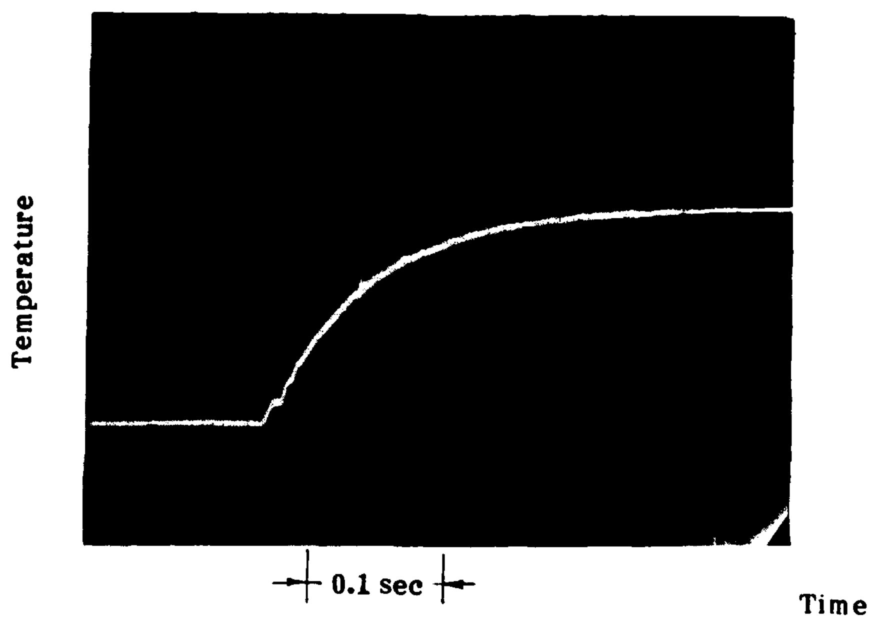


FIG. 4 TYPICAL THERMOCOUPLE RESPONSE

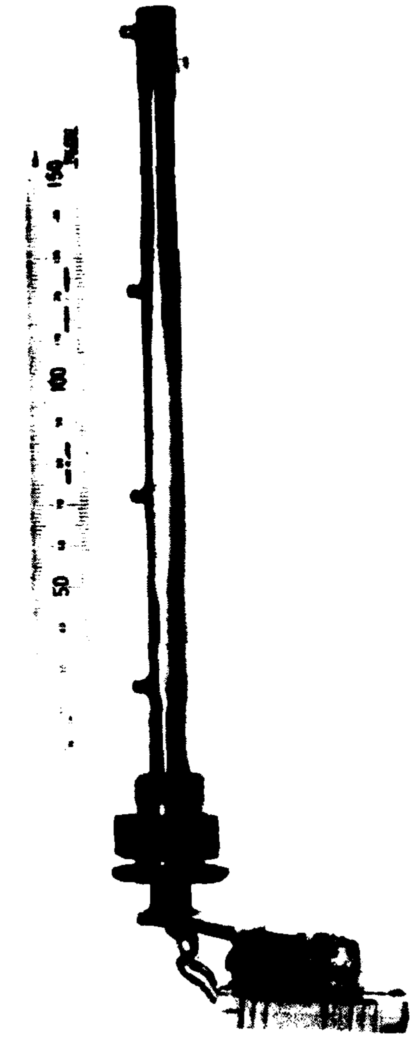


FIG. 5 THERMOCOUPLE PROBE

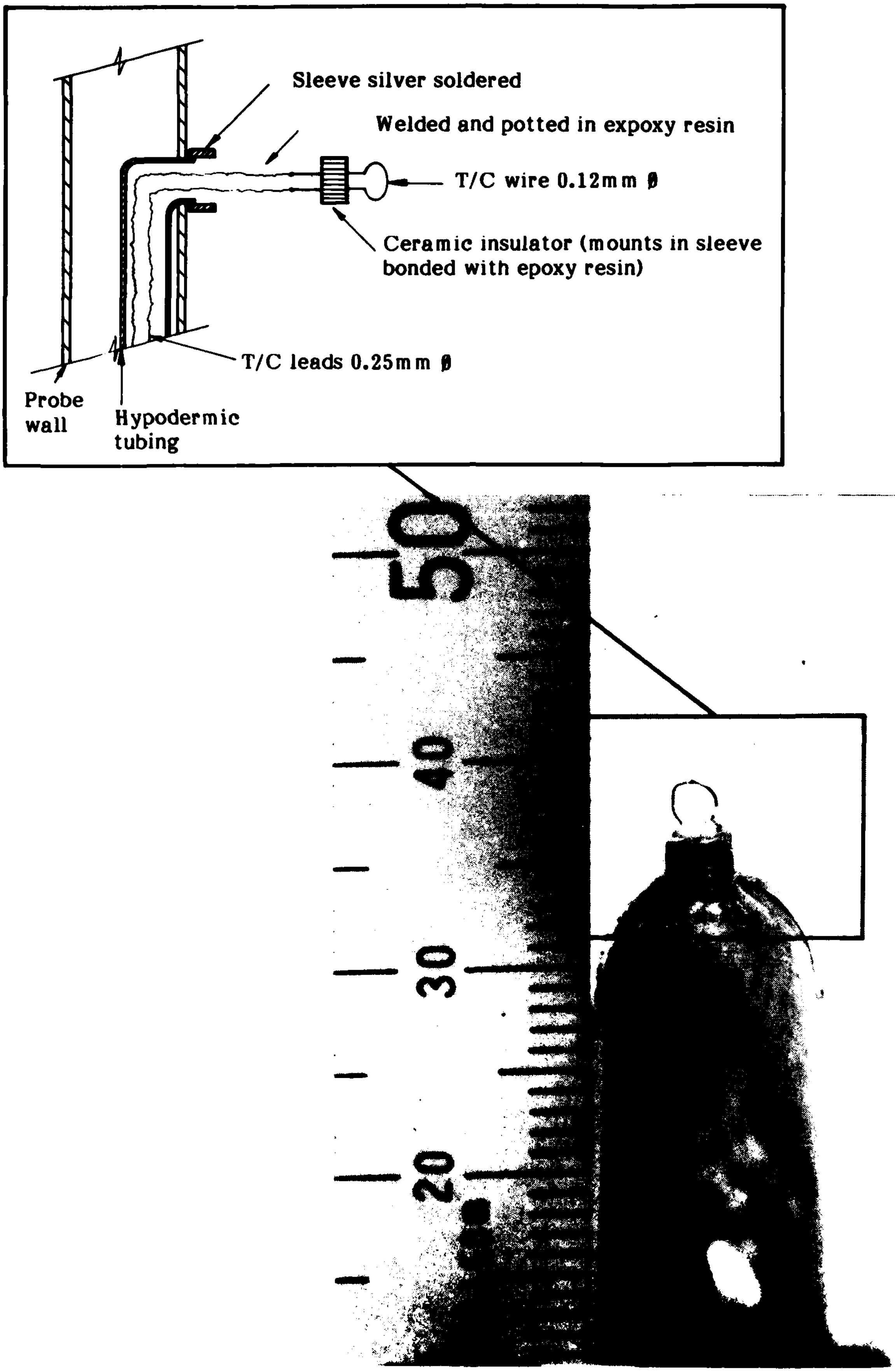
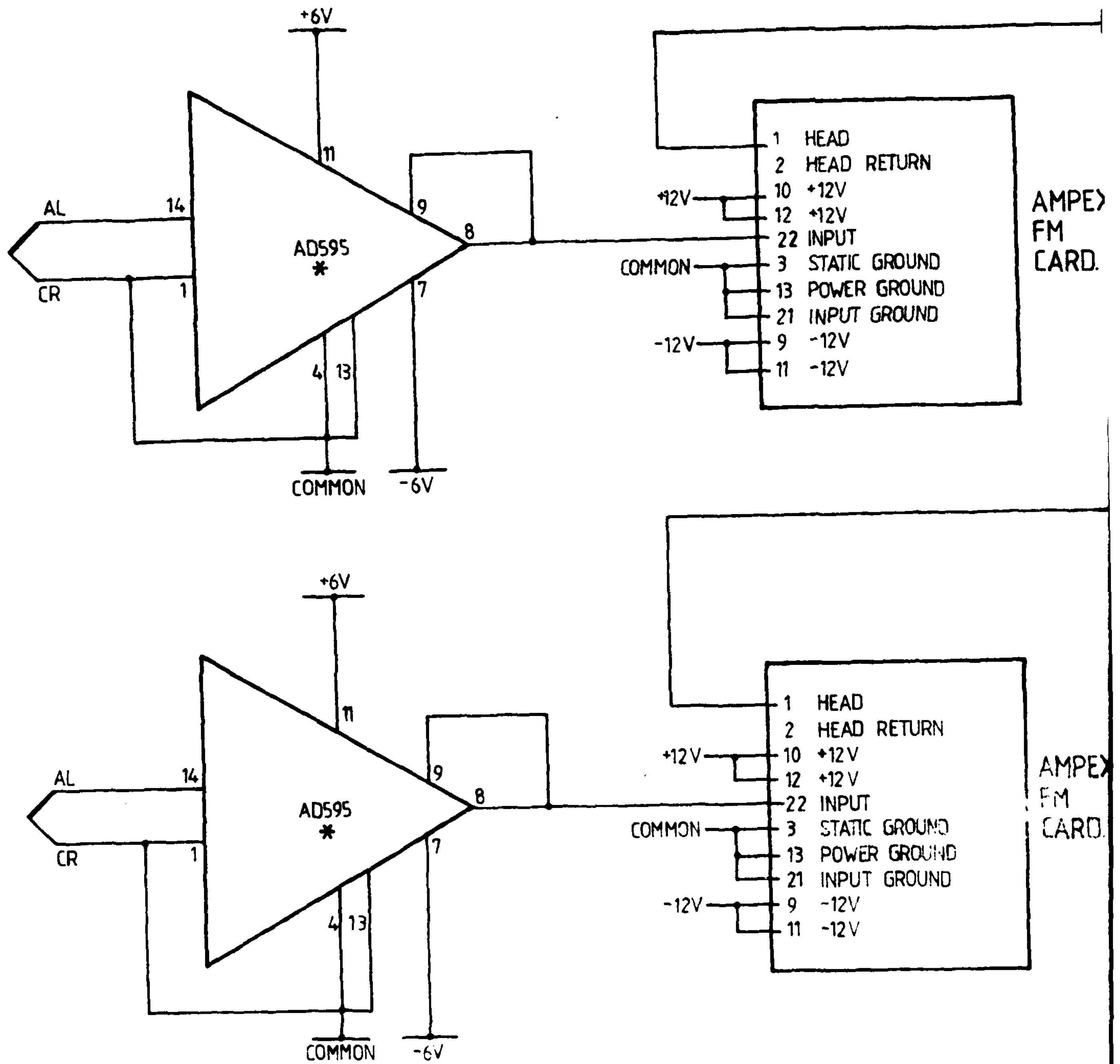


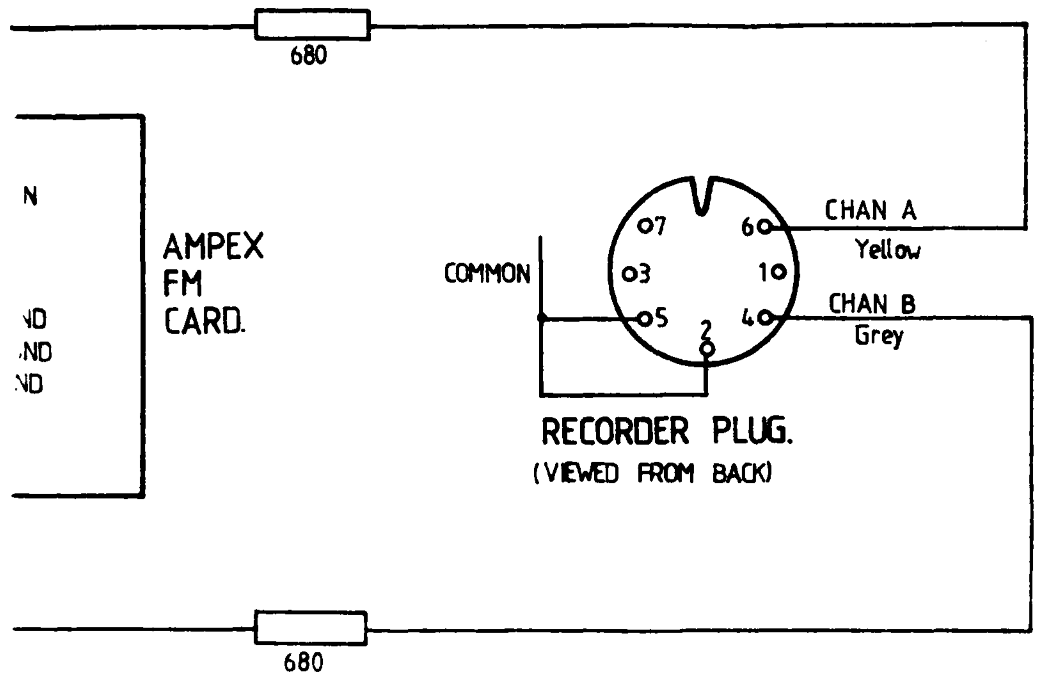
FIG. 6 DETAILS OF SENSOR CONSTRUCTION

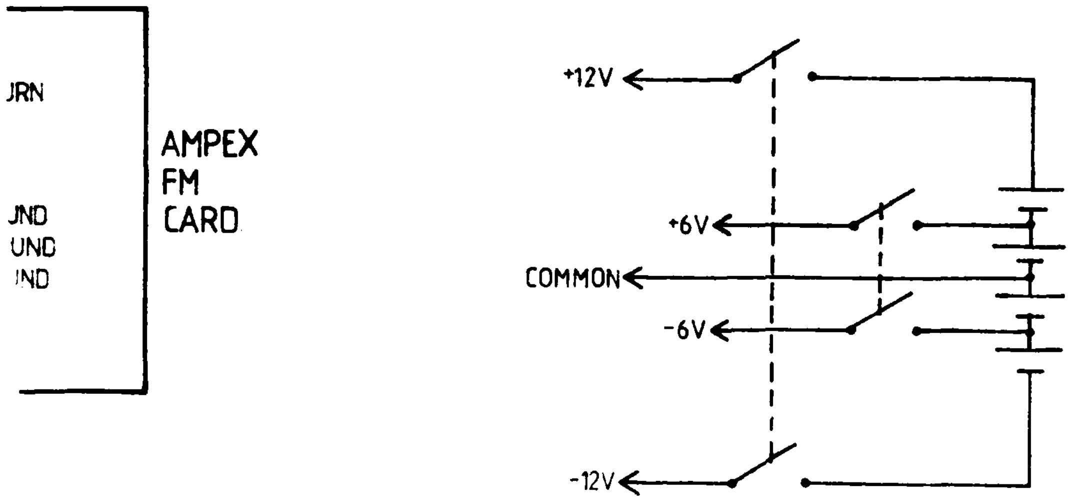


* INCLUDES ICE POINT COMPENSATION.

FIG. 7 SIGNAL CONDITIONING CIRCUIT

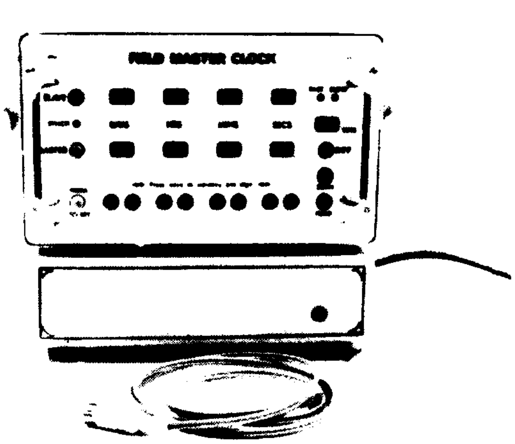
1 of 2


680
AMPEX
FM
CARD.
COMMON
7
3
5
2
6
1
4
CHAN A
Yellow
CHAN B
Grey
RECORDER PLUG.
(VIEWED FROM BACK)
680


AMPEX
FM
CARD
+12V
+6V
COMMON
-6V
-12V

(a)

(c)



(b)

FIG. 8 RECORDER COMPONENTS

(a) Speech time recorder

(b) Field Master clock

(c) Field replay unit

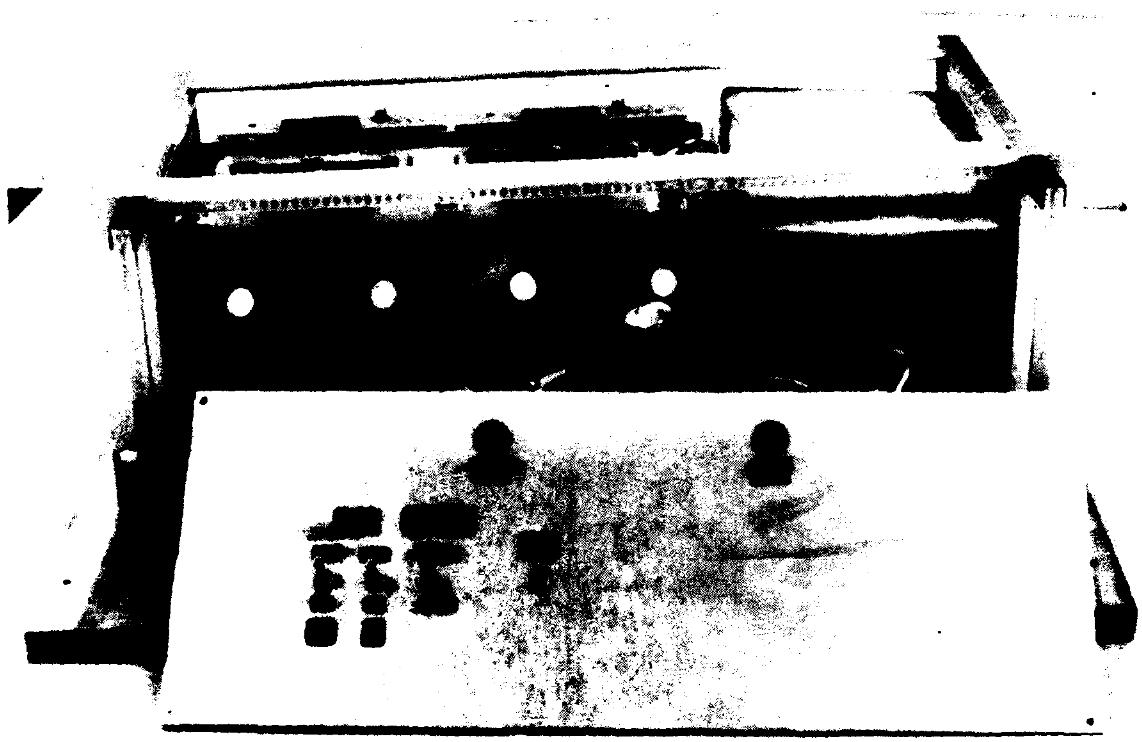


FIG. 9 INSTRUMENT PACKAGE CONSISTING OF SIGNAL CONDITIONING RECORDER AND POWER SUPPLY

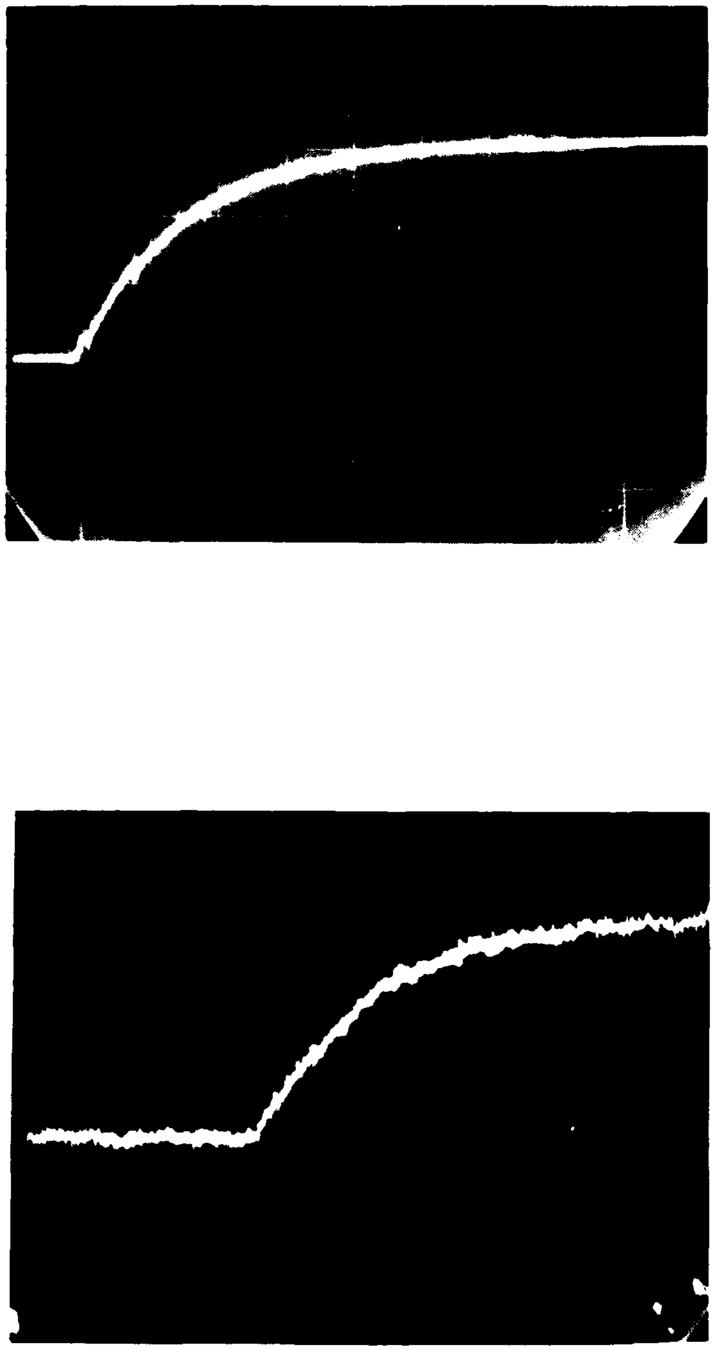


FIG. 10

UPPER TRACE - Thermocouple transient response (AD595 output)

LOWER TRACE - Playback of record transient response

Sensitivity - 0.2 volts/cm

Time base - 50 ms/cm

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Thermocouples
Temperature measuring instruments
Jet engine inlets
Atar 09C engine

15. COSATI Group
21050

16. Abstract

The development and operation are described of a fast response temperature probe and associated instrument package for the in-flight recording of air temperature variations in the inlet to the Atar 09C engine of the Mirage IIIO Aircraft.

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